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A METHOD FOR DETECTING DAMAGE TO ROLLING BEARINGS IN TOOTHED GEARS OF PROCESSING LINES

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This paper presents a method of diagnosing damage to rolling bearings in toothed gears of processing lines. The research has shown the usefulness of vibration signal measurements performed with a laser vibrometer and of the method of denoising signals by means of a discrete wavelet transform in detecting damage to bearings. The application of the method of analysis of the characteristic frequencies of changes in the vibration signal amplitude made it possible to draw conclusions about the type of damage to the bearings.

Key words: bearing, gear, damage, condition monitoring, vibration

INTRODUCTION

Damage to single components of processing lines used in metallurgical companies may lead to a temporary stoppage even of a whole production process. The selection of materials from which the particular components are to be made, and their treatment, play a crucial role. To ensure the reliable operation of processing lines in metallurgical companies, continuous monitoring of their technical condition should be performed, with particular attention paid to the elements subject to considerable mechanical and thermal load, and to the elements susceptible to accelerated wear [1-3].

Toothed gears are the components of processing lines in metallurgical companies in which shaft bearings get damaged quite frequently [4]. To ensure their long-term and reliable operation, new methods are being developed to assess their momentary technical condition. These methods are oriented to the detection of damage in bearings in its early phase.

To diagnose the above-mentioned types of damage, the methods proposed in [1-3, 5-8] for the measurement, processing and analysis of vibroacoustic signals can be used. The vibration measurement methods carried out by means of laser vibrometers are particularly useful in metallurgical companies. They enable contactless examination in places difficult to access or from a considerable distance, as well as at a high temperature in the measuring point.

The paper presents the results of research whose purpose was to develop a method of diagnosing damage to rolling bearings in a toothed gear shaft. Stand tests were performed, where the vibration signals of a toothed gear with simulated different types of bearing damage were recorded. For processing the signals, a method of bearing damage detection was used. It consists in the filtration of the vibration signals by means of denoising, which is then calculated using a discrete wavelet transform [9-10]. Next, in the assessment of the damage to the bearings, the developed method of analysis of the characteristic frequencies of changes in the vibration signal amplitude was applied.

RESEARCH METHOD

Tests were conducted on a power circulating gear testing machine, FZG (DIN 51354). During the tests, the shafts of the FZG power circulating test stand were propped by ordinary ball bearings. Measurements of the velocity of transverse vibration of the gear shaft were performed using a laser vibrometer (Figure 1). The experiment was carried out at a unit load intensity of Q = 3,15 MPa.

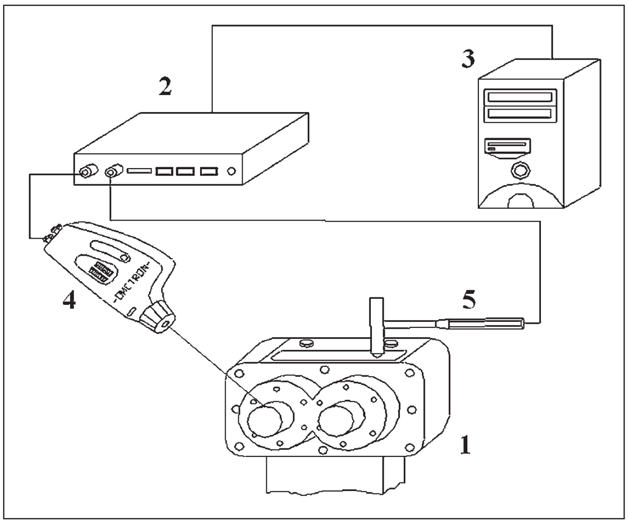

Figure 1 The diagram of measurement system: 1 – the examined gearbox, 2– DSTP signal analyzer (SigLab), 3– logic system, 4–laser vibrometer, 5 – modal hammer

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As part of the research, an evaluation was made of the resonance structure of the gear shaft, on which bearings in different technical conditions were installed. Measurements were performed in accordance with the assumptions of the experimental modal analysis, determining the specific transmittance of the measuring point (Figure 1). VIOMA software [11] working in the Matlab environment was used for the analysis. In the test-stand experiments, a bearing in good condition was used (Table 1) as well as bearings with damage of different types, made in an artificial way (Figure 2 a-b), and a bearing with advanced wear caused by long-term operation in a mining pump (Figure 2 c-d). The characteristic frequencies of the vibration signal which occurred as a result of damage to the bearing were calculated based on the dependencies presented in [4].

The frequencies of vibration caused by single damage, when there is no spin in the bearing race, amounted to: outer raceway 90,1 Hz and inner raceway 130 Hz. At the same time, no distinct characteristic frequencies were found in the spectrum of the vibration signal emitted by the worn out bearing.

SIGNAL PROCESSING METHOD

In the process of identifying the vibration signals, the resonance of the gear shaft was calculated by determining the function of transition between two signals, x(n) and y(n), based on dependence (1) [11]:

$$\hat{H}(\omega)=\frac{\hat{P}_{xy}(\omega)}{\hat{P}_{xx}(\omega)} \qquad (1)$$

where:

$\hat{P}_{xy}(\omega)$ - common power spectral density (CSD) of signals x(n) and y(n),

$\hat{P}_{xx}(\omega)$ - power spectral density (PSD) of signal x(n).

Table 1 **Rolling bearing parameters**

Parameter B.1	Value	
	B.2 i B.3	
Inner diameter / mm	35	35
Outer diameter / mm	80	80
Pitch diameter / mm	57,25	59,85
Ball diameter / mm	14,25	14,25
Number of balls / -	8	7

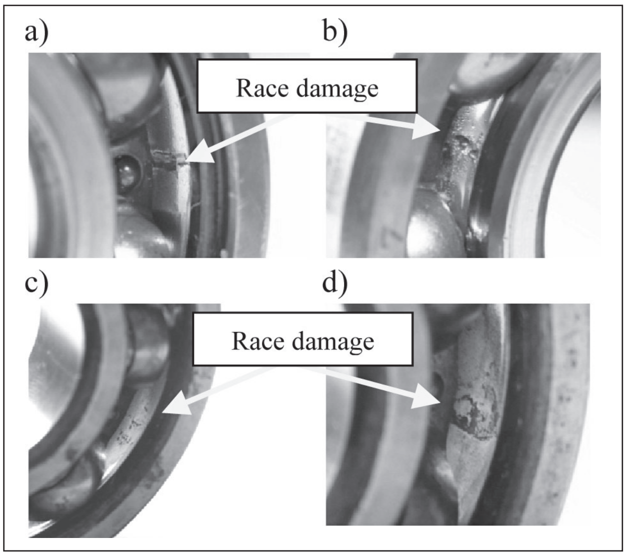

Figure 2 Damage of the bearing: a) bearing with a damaged outer race (B.1), b) bearing with a damaged inner race (B.2), c)-d) bearing damaged in service (B.3)

To process the recorded signals of transverse vibration velocity of the gear shaft where bearings in different technical conditions were installed, a denoising algorithm was used, calculated on the basis of a discrete wavelet transform, consisting of [9-10]:

- decomposition of the vibration signal,
- assumption of the threshold coefficient and of the number of decomposition levels,
- cutting off the noise at each decomposition level,
- signal reconstruction.

After the denoising procedure had been completed, the characteristic frequencies of changes in the vibration signal's momentary amplitude were determined. A distribution of the so-calculated "characteristic frequencies" on a two-dimensional frequency-frequency plane makes it possible to draw conclusions about the possible damage to the gear bearing.

RESULTS AND DISCUSSION

The measurement results of the specific transmittance of the gear shaft presented in Figure 3 indicated a considerable resonance of the shaft at a frequency of ca. 1,2 kHz.

Figure 4 shows the calculated spectra of transverse vibration velocity of the gear shaft, near which the bearings were changed. As results from the spectral calculations, when bearings in different technical conditions were installed in the gear, their damage generated a clear increase in the vibration amplitude within the resonance frequency of the gear shaft. The occurring spectral stripes did not generate any explicit changes corresponding to the damage present in the bearing, which was caused by the sliding of the bearing. This made it impossible to explicitly determine the damage to the gear.

In further tests, a denoising procedure was applied [9-10] for processing the recorded vibration velocity signals, assuming the following values for the calculations: Daubechies 2 wavelet, number of decomposition

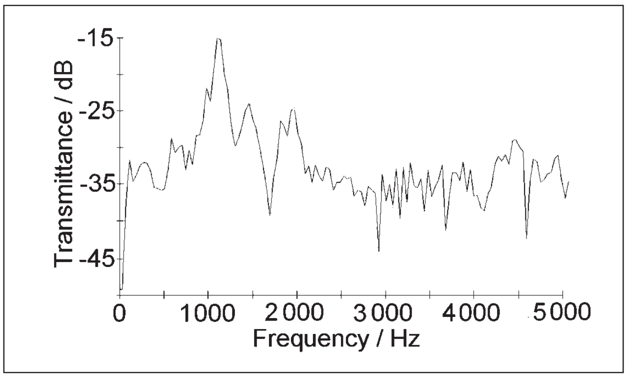

Figure 3 Transmittance of the gear shaft

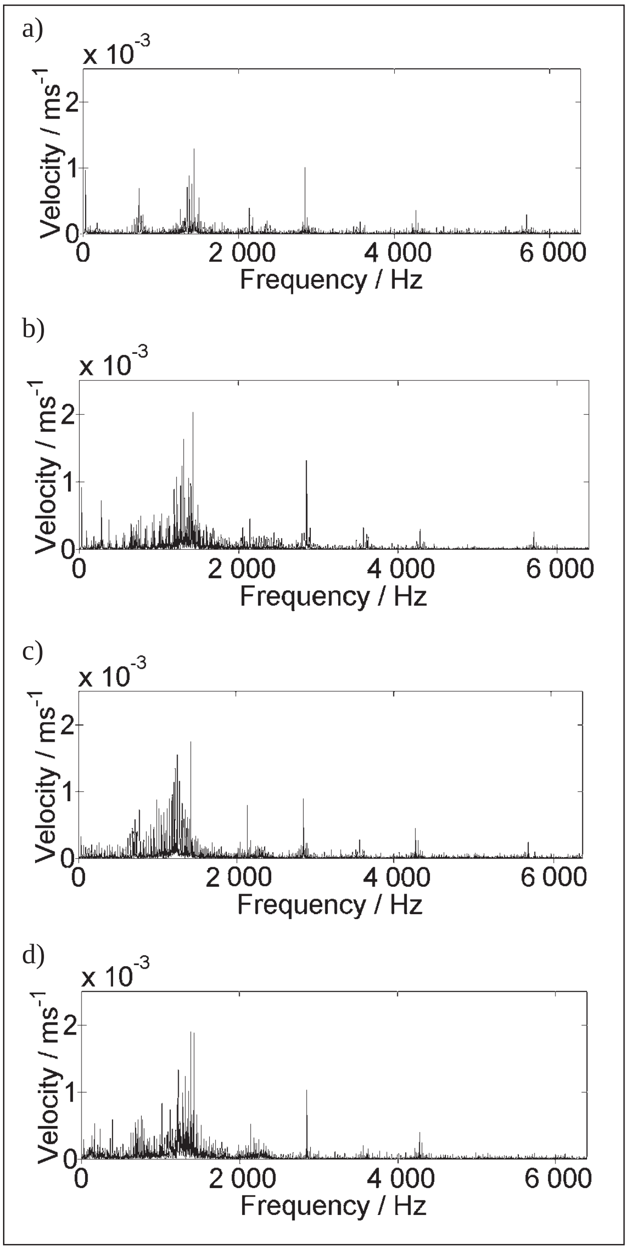

Figure 4 Vibration signal spectra for a case involving the bearing: a) in good condition, b) with a damaged outer race, c) with a damaged inner race d) damaged in service

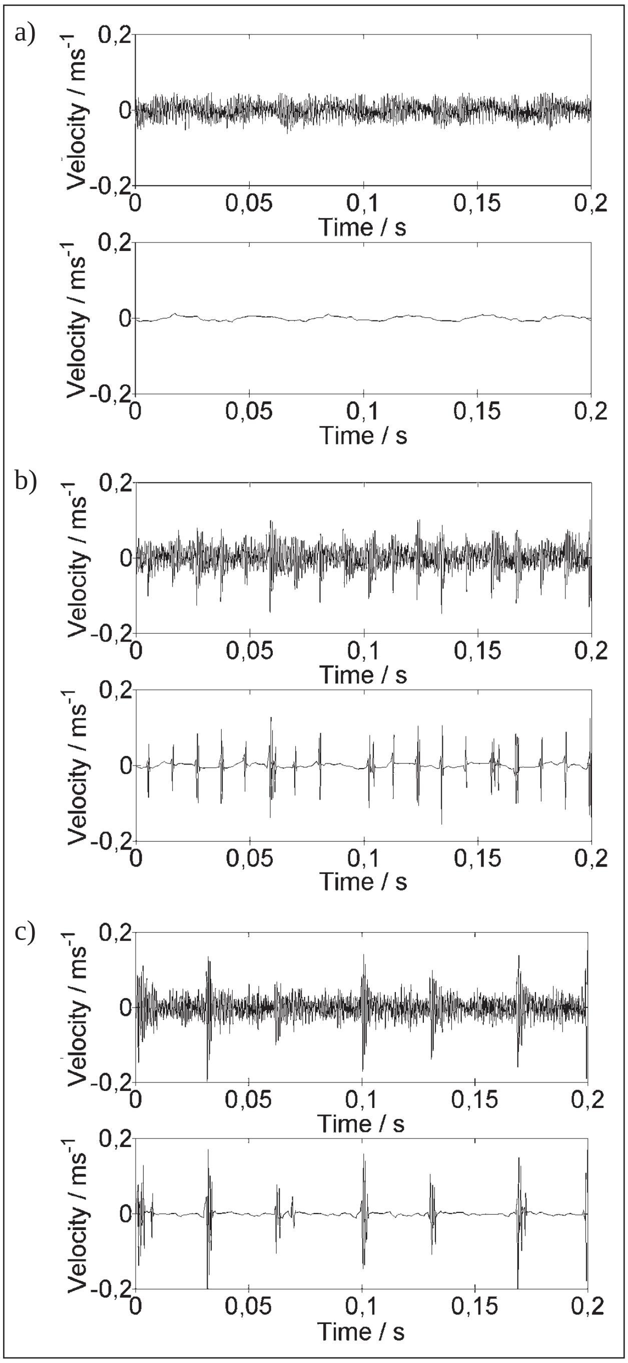

Figure 5 Examples of vibration signals before and after denoising: a) bearing in good condition, b) bearing with a damaged outer race, c) bearing with a damaged inner race

levels = 6, threshold value = 0,15, and hard thresholding. Figure 5 presents examples of vibration signals before and after denoising.

The tests performed show that the procedure of denoising the vibration signal facilitated highlighting the characteristic changes in the amplitude of vibration caused by local damage to the bearings. The denoising also enabled removing the insignificant signal constituents which were treated as noise in the analysis.

Figure 6 contains the frequency-frequency distributions of the characteristic frequencies of changes in the vibration amplitude, caused by bearing damage of different types.

In these distributions, the intersection point of the X-axis and Y-axis represents the signal recorded for the gear with undamaged bearings. In the frequency-frequency distribution of the vibration signal of the bearing with a damaged outer race, the characteristic frequencies are observed in the range of the determined damage frequency of 90,1 Hz and its divisibility by 2. In the case of damage to the inner race, the distribution of the characteristic frequencies falls mostly within the range of divisibility of the damage frequency (130 Hz) by 3, 4, 5 and 7. These values are connected with the rotation of the inner race in relation to the direction of the force acting between the gear teeth. The distribution of the characteristic frequencies obtained for the bearing worn out in service is a proportional distribution in the range above 30 Hz, which results from the random occurrence of damage on the surface of the bearing race and balls.

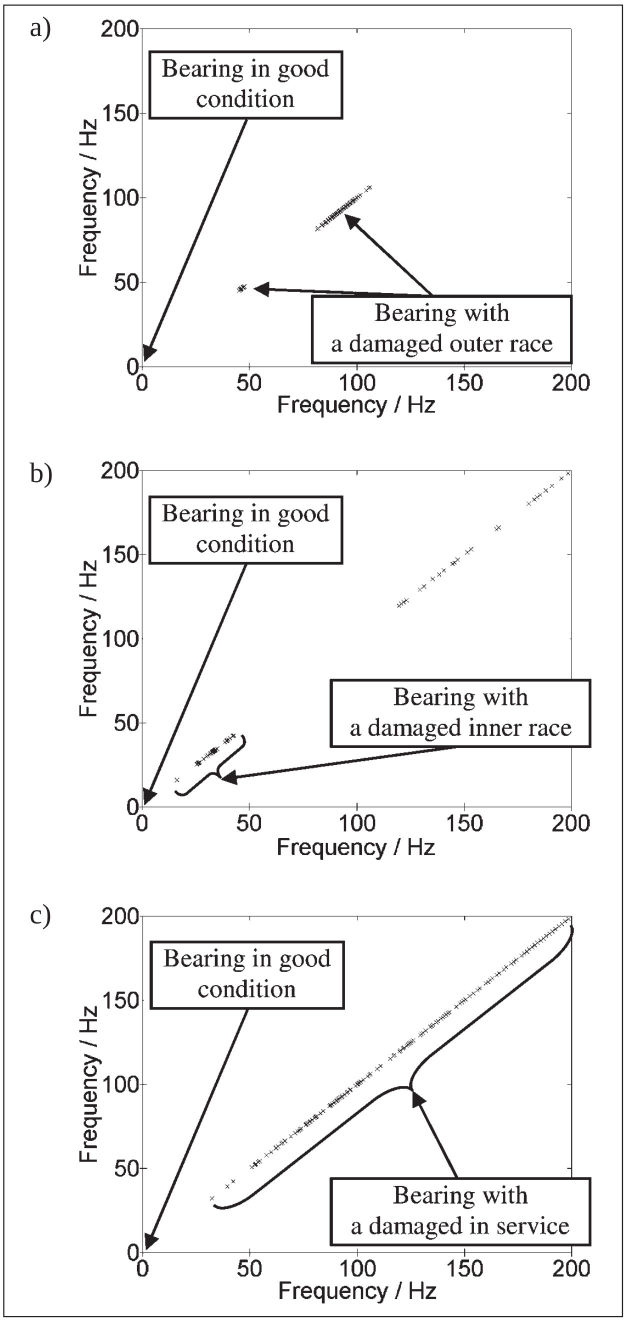

Figure 6 Frequency-frequency distributions of the characteristic frequencies of damage occurrence in bearings with: a) a damaged outer race, b) a damaged inner race, c) damaged in service

CONCLUSIONS

The paper presents a method of diagnosing damage to bearings in toothed gears of processing lines used in metallurgical companies by means of the recording and processing of vibration signals. The application of a laser vibrometer enabled making measurements of vibration of the gear in the vicinity of damaged bearings. The vibration signal denoising procedure based on the calculations of the discrete wavelet transform allowed the removal of noise from the signal and enabled bringing out the information about damaged bearings. The developed method presented in the paper to evaluate the characteristic frequencies of changes in the momentary vibration signal amplitude by means of frequency-frequency distributions enables diagnosing simulated damage to shaft bearings in the toothed gears of processing lines used in metallurgical companies.

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Note: The responsible translator for the English language is A. Nowak, Chorzow, Poland